The dynamics of spatial structures in the rural commune of Sourgou (Burkina Faso): an analysis based on ecological indices

La dynamique des structures spatiales dans la commune rurale de Sourgou (Burkina Faso) : une analyse à partir des indices écologiques

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Abstract

The land of the rural commune of Sourgou is under anthropic pressure through the extent of rain-fed and irrigated agricultural practices. Its agrarian landscape, like that of other rural communes in Burkina Faso, is changing. The objective of this study is to characterize and evaluate the landscape dynamics of the spatial structures of the rural commune of Sourgou from 2002 to 2021. It was made possible through the application of mainly rural landscape ecology procedures in combination with remote sensing data collection and analysis methods with the 2002 National Topographic Data Base and a 2021 sentinel satellite image. Statistical calculations of indices and areas of the different occupation units as well as the realization of land use maps were carried out. The results show a greater fragmentation (change) of all land use units (savannah, orchards, water surfaces and bare soil) except for rainfed crops which show less fragmentation over the entire study series (2002-2021). Also, the calculation of spatial extension rates shows an evolution of bare soil and water surfaces in the study area at respective rates of 9.21% and 0.73% and a regression of the surface area of savannahs (- 1.45%), orchards (-2.49%) and rainfed crops (-6.00%). Some land use units such as bare soil (0.03 km2), savannah (1.56 km2) and fields (0.99 km2) lost their areas to water surface classes, while orchards (0.37 km2), savannah (18.40 km2), fields (6.66 km2) and watercourses (0.10 km2) converted to bare soil.

Keywords

Land use units; index-fragmentation; spatial extension rate; Sourgou; Burkina Faso.

Résumé

Les activités agricoles, qu'elles soient pluviales ou irriguées, exercent une pression anthropique considérable sur les terres de la commune rurale de Sourgou. Son paysage agraire, tout comme celui des autres communes rurales du Burkina Faso connaissent un changement. Cette étude a pour objectif de caractériser et d'évaluer la dynamique paysagère des structures spatiales de la commune rurale de Sourgou de 2002 à 2021. Elle a été possible grâce à des procédés d'écologie du paysage principalement rurales additionnés aux méthodes de collectes et d'analyses de données de télédétection avec la Base Nationale de Données Topographiques de 2002 et une image satellitaire sentinelle de 2021. Les calculs statistiques des indices et celles des superficies des différentes unités d'occupation ainsi que la réalisation des cartes d'occupation du sol ont été réalisés. Les résultats révèlent une fragmentation accrue de toutes les catégories d'occupation du sol (savane, vergers, surfaces d'eau et sol nu), à l'exception des cultures pluviales qui présentent une fragmentation moins prononcée sur toute la période étudiée (2002-2021). Aussi, les calculs des taux d'extension spatiale montrent une évolution des sols nus et des surfaces d'eau dans la zone d'étude avec des taux respectifs de 9,21% et 0,73% et une régression de la superficie des savanes (-1,45 %), des vergers (-2,49 %) et des cultures pluviales (-6,00 %). Certaines unités d'occupation tels que les sols nus (0,03 km2), les savanes (1,56 km2) et les champs (0,99 km2) ont perdu leurs superficies au profit des classes de surfaces d'eau, tandis que les vergers (0,37 km2), les savanes (18,40 km2), les champs (6,66 km2) et les cours d'eau (0,10 km2) se sont convertis en sols nus.

Mots clés

Unités d'occupation du sol; indice-fragmentation; taux d'extension spatiale; Sourgou; Burkina Faso.

1. Introduction

The evolution of the population goes hand in hand with the growth of food needs (Cambrezy et Sangli 2018). It is also materialized by a great dynamic of the different land use units (Kékélé 2015). Indeed, rainfed and irrigated crop fields due to numerous clearings are gradually replacing the natural landscape (Yaméogo et al. 2020). Often, the latter gives way to a much more anthropized environment where fruit trees proliferate (Traoré et al. 2021) or bare surfaces, profoundly transforming the agrarian landscape. These bare soils could be explained by poor cultivation practices such as the use of pesticides and herbicides; they appear in the form of water-impermeable glacis that are difficult to exploit (Idani et al. 2021). Hence a great dynamic of land use in rural areas (Bouko et al. 2007).

The commune of Sourgou, like other communes, is experiencing an accelerated increase in its population. According to data from the RGPH (General Census of Population and Housing), the population has increased from 13,709 in 2006 to 1,732 in 2019. This increase in population in Sourgou is the cause of land clearing for agricultural purposes. The study site is experiencing a great deal of dynamism in terms of agricultural units, which is manifested in the expansion of fields and irrigated areas to the detriment of natural landscapes such as savannahs and forest relics. The degraded agricultural surfaces or in the

process of degradation, because of their fertility, are abandoned to the profit of other lands. This leads to an increasing visibility of bare soil on both sides of the commune (Bouda 2020). The objective of this study is to characterize and evaluate the landscape dynamics of the land use units of the aforementioned commune from 2002 to 2021 based on spatial structure indices such as the form index, dominance, and the spatial expansion rate.

2. Materials and methods

This section presents the physical and human characteristics of the study area as well as the materials and methods used for data collection and processing. The land use dynamics of the study area between 2002 and 2021 is analyzed from the land use status and spatial expansion rate calculations.

2.1 Study area

With a density of 65.90 inhabitants per square kilometer, the rural commune of Sourgou covers an area of 266.03 km2. It is one of the 14 rural communes of the Boulkiemdé province. It includes five villages: Sourgou (the commune's capital), Ouoro, Rogho, La, Kougsin and Guirgo. It is located 15 km from the provincial capital Koudougou and 10 km from the commune of Sabou on the national road n°13 Koudougou-Léo, between longitude 12°30' W, and latitude 2°09' N. It is bordered to the west by the commune of Tenado, to the north by the communes of Koudougou and Ramongo, to the south by the commune of Sabou, and to the east by the commune of Poa (Figure 1).

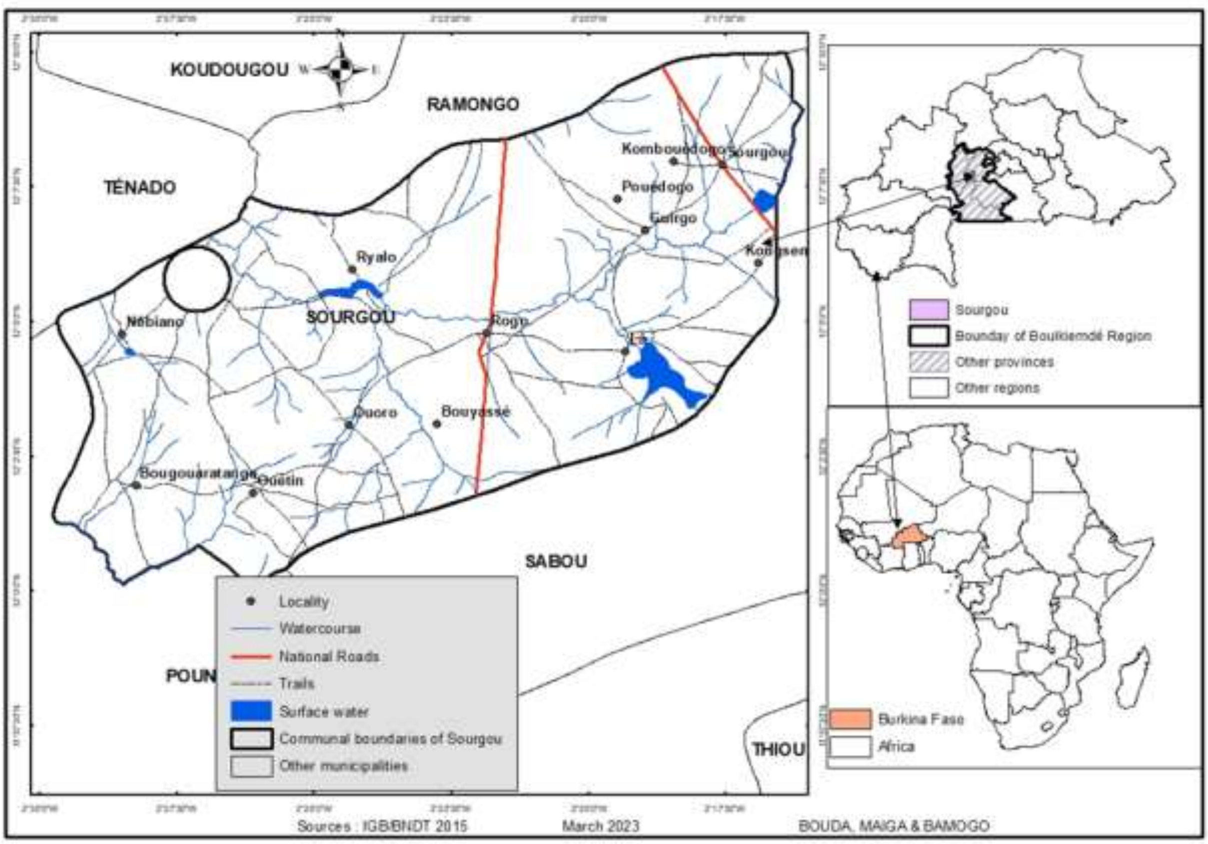


Figure 1. Geographic location of the study area

The commune of Sourgou has a relatively flat terrain. The main soil types encountered are leached or depleted tropical ferruginous soils, poorly developed soils with gravelly erosion, hydromorphic tropical ferruginous soils with or without induration, and Vertisols (Sigué H et al. 2011), with a dominance of lithosols on cuirass and ferruginous soil. Hydromorphic soils with low humus to pseudogley surface are located in the lowlands and along water bodies. The presence of these soil types also encourages clearing for market gardening and irrigation (Maïga et al. 2021). Agriculture is the main activity of the population of Sourgou.

The vegetation is of the tree savannah type, sparsely populated with shrubs. This savanna is dominated by species such as Vitellaria paradoxa, Bombax costatum, Tamarindus indica, Parkia biglobosa, Saba senegalensis, Anogeissus leiocarpa, Acacia albida, Khaya seneglensis, Lannea microcarpa, Guiera senegalensis, Annona senegalensis. The herbaceous stratum consists of Andropogon gayanus, Loudetia togoensis, Pennissetum pedicellatum. There are also exotic trees such as Azadirachta indica, Mangifera indica and Eucalyptus camaldulensis which are artificial plantations (Ouédraogo et al. 2022).

The hydrography of the study area shows four water bodies. It is crossed by a main watercourse (river), a tributary of the Mouhoun watershed (Ouédraogo et al. 2022).

Several methods were used in this study.

2.2. Methodology

The methodological approach is based on documentation, Geographic Information System and Remote Sensing techniques. It introduces all the tools, collection materials and techniques for processing or analysing the data

- **Materials**

The analyses of the spatial and temporal dynamics presented in the study were possible thanks to the exploitation of the BDOT 2002 and of the sentinel image downloaded from the website www.usgs.gov (Table 1) (Sekertekin and al. 2017). The month of November was chosen because it is an intermediate month between the rainy season and the dry season. At this time of year in the study area, crop residues are still visible, allowing them to be distinguished from bare soil. The areas of the occupation units were evaluated using ArcGis software and the Excel spreadsheet (Atta et al.2016).

Table 1. Sentinel Image Metadata

Data set attribute	Attribute value
Entity ID	L1C_T30PXU_A024730_20211130T104009
Start date acquisition	2021-11-30T10:40:09.568Z
End date of acquisition	2021-11-30T10:49:57.635Z
Cloud cover	0,8042
Platform	SENTINEL-2B
Orbit number	108
Band ID ofdata	S2B_OPER_MSI_L1C_DS_VGS2_20211130T123558_ S20211130T104009_N03.01
Data	WGS84 UTM 30N
Resolution	10, 20, 60 METERS

Source : www.usgs.gov., January 2022

The satellite images were processed with ENVI 5 and the ArcMap extension was used for the various statistical calculations of the areas and for the output of the land use maps.

Also, the GPS tool was used to survey the geographic coordinates of the occupation units.

- **Pre-treatment**

For the pre-processing of the sentinel image, a false color composition was performed (Figure 2) using the 542 bands. The 542-composition made it possible to visualize the different occupation units of the soil of the commune of Sourgou in the order of the visible. In other words, the false color composition allowed for better identification of colors such as blue; green and red clearly visible from this composition (Sekertekin and al. 2017).

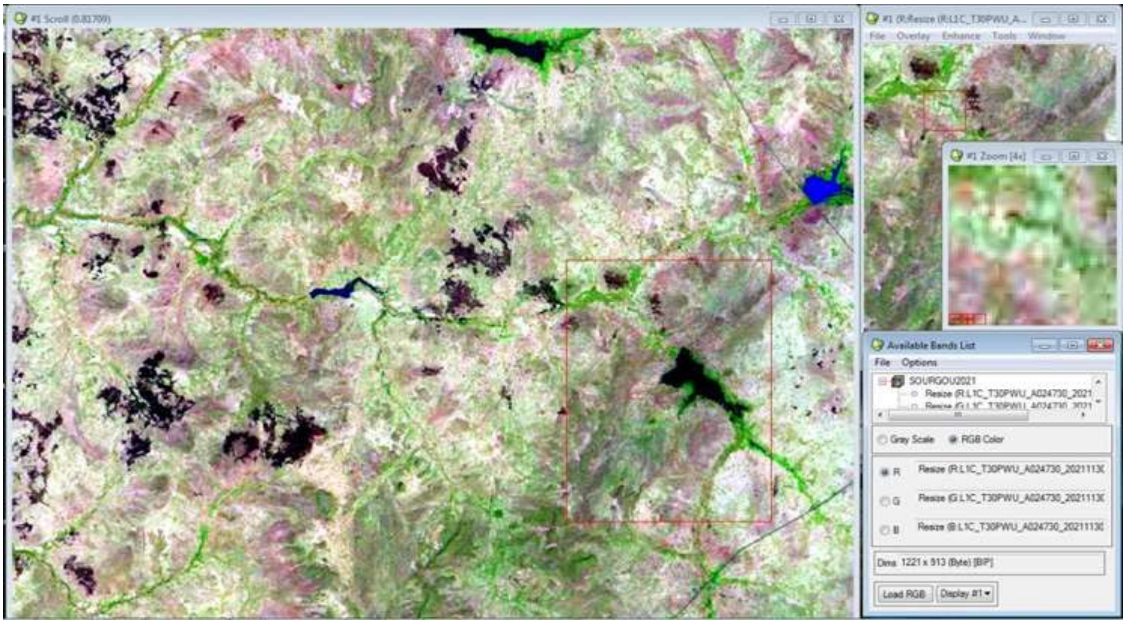


Figure 2. RGB color composition of the 2021 sentinel-2B image

Source: Sentinel-2B 2021 image; laboratory work

Legend: **Blue:** water bodies; **bluish green:** savannah; **purple:** bare ground; **yellow and brown:** fields; **green:** fields; blue: fields; green: fields; clear: orchard.

- **Field stage**

The field stage consisted of geographic coordinate surveys for verification. This step is important because it allows the taking of field samples from GPS (Global Positioning System) which will be used as supports for the identification of occupation units on the images (Ducrot 2005). The surveys also serve to validate the selected ROI (Regions Of Interest), as well as the classification of the 2021 image. A total of 42 points were surveyed.

- **Data processing**

The methodology adopted for processing the 2002 BDOT is somewhat different from the 2021 sentinel image for this study. For the 2002 BDOT, the occupancy units were first transformed into ROIs. These ROIs facilitated the conversion to raster. The image being then classified and having the desired occupation units, we did not see the need to proceed to post classification (smoothing process according to various algorithms). The goal was to make a correlation between the different units of occupation for the realization of the transition matrix necessary for the study.

As for the sentinel image of 2021, the processing was done according to a supervised classification of "maximum likelihood" and a post classification from the smoothing algorithm "Majority/Minority Analysis" (Caloz et Pointet 2002). The choice of supervised classification was motivated by our knowledge of the study area (Ouarab et al.1999). The different classes determined and then vectorized were used for the realization of the land use maps (Caloz et Pointet 2002).

- **Index Calculations**

Some indices such as form index, dominance index and spatial expansion rate were also calculated.

- **Form index (FI)**

The shape index is based on the principle of the ratio of perimeter to area. According to Ducrot (2005), quantifying shape is very difficult. However, the shape is a key element for the interpretation that shows the degree of anthropization of a space. The larger the perimeter for a given area, the less compact or more elongated the object will be, and the greater the distance of contact at the location of the disturbance (Bogaert and al. 2000). It also reflects the degree of anthropization (Ducrot 2005).

The class form index (IF) was calculated using the following formula (Ducrot 2005):

$IF= (0,25\times P) /\sqrt{a}$

Where, "P" is the sum of the perimeters of the tasks in a given class, and "a" is the sum of the areas of the tasks in the same class. "0.25" represents the normalization term due to the square shape of the base element. The perimeter and area of the tasks were calculated from the attribute table of the different classes.

- **The dominance index (D)**

The dominance "D" indicates the proportion of area occupied by the dominant patch in the class. It was determined by the formula of Mouhamadou et al. (2012):

$\boldsymbol{D} = (\boldsymbol{amax} \div \boldsymbol{a}) \times \mathbf{100}$

amax= total area occupied by the largest spot of a given class

For example, if for a given occupancy unit (Savannah in 2002): max area =26.90; and area =105.35; the dominance index D is calculated as follows: D =26,903/105,359*100 = 25,53.

The higher the dominance value, the less fragmented the class.

- **Rate of spatial expansion**

The average annual rate of spatial expansion is calculated over all land use units. It shows the spatial evolution of the different land units in a given year series. It was determined from the formula of Puyravaud (2003).

$T=(\ln S2-\ln S1) /(t2-t1) \times \ln e \times 100$

S1 represents the area of a given class at date t1; S2 the area of the same class given at date t2 and lne the base neperian logarithm e (2.71828). The methodology presented above provided results that were analyzed and interpreted.

3. Results and Analysis

From the analyses, it appears that the different areas of the land use units have all undergone an evolution materializing by a decrease of their units towards other classes, except for bare soil and water surfaces which have experienced an increase in their

areas (Table 2). Finding a plausible explanation for these changes in surface area led to the calculation of various indices, such as the form index and the dominance index.

The shape index tells us about the shape of the different tasks. The tasks can have regular or complex shapes depending on the degree of anthropization. As an illustration, a rounded shape indicates human control over these occupation units. As for the results, we note an evolution of the number of spots (N) of the various occupation units because they passed from 76 spots in 2002 to 3139 spots in 2021. The shape indices have thus increased over the whole series. Indeed, classes such as savannahs, rainfed crops and bare soils have respectively increased by 64, 69; 51, 31; 32, 05 in 2021, compared to their values in 2002. These high values reflect the irregular and complex forms of the different tasks that compose them. However, some formations such as orchards and water bodies present respective shape indices of 7.20 and 8.5 in 2021, which means that these different occupation classes present more or less polygonal shapes (circular or triangular).

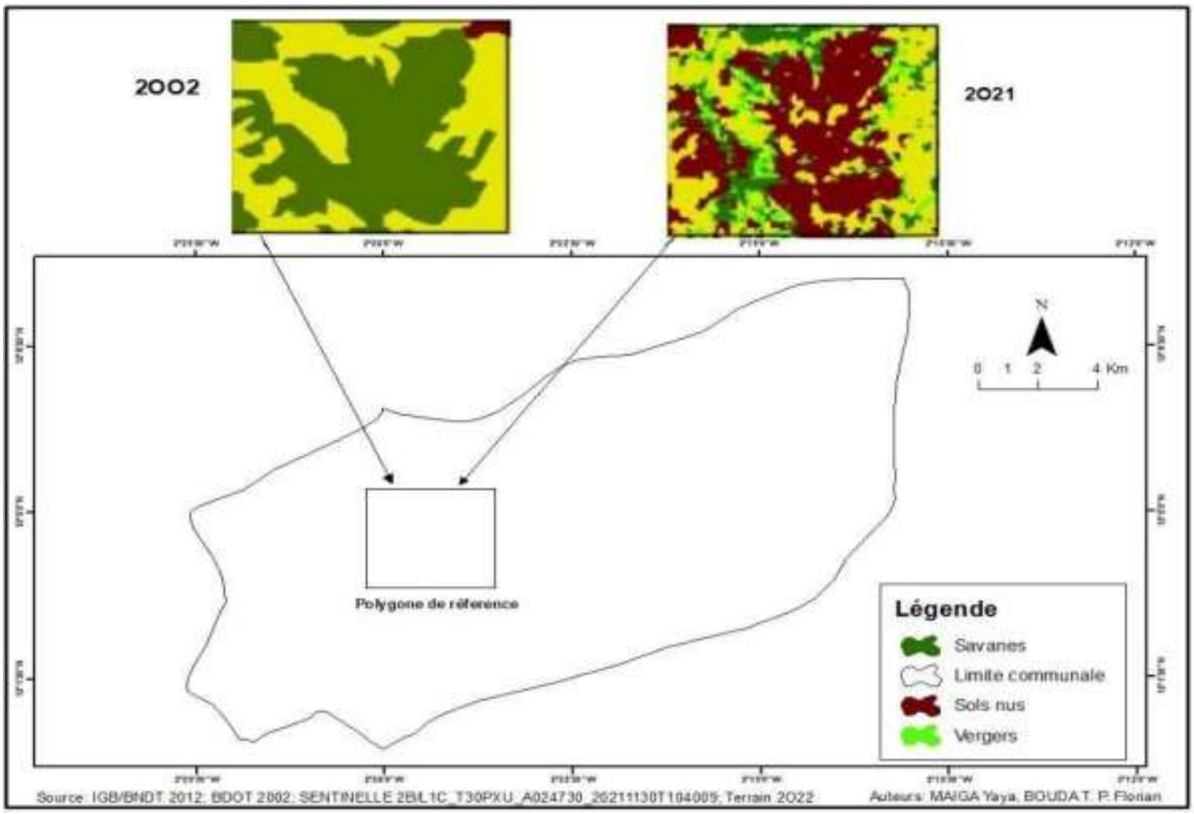


Figure 3. Illustration of a fragmentation of occupation units (Savanna and rainfed crops) inthe commune of Sourgou

Table 2. Presentation of calculated indices and landscape dynamic

	2002					**2021**					
Units Occupations and num berof tasks	Areas (a in km2)	**Perimeters (p in km)**	**Index of Form (IF)**	**A max**	**Dominance (D)**	**Units Occupations and num berof tasks**	**Areas (a in km)**	**Perimeters (p)**	**Index of Form (IF)**	**A max**	**Dominance (D)**
Savannah (N= 36)	105.35	469.53	11.43	26.90	25.53	**Savannah (N=1727)**	101.50	2607.34	64.69	11.01	10.85
Orchard (N=5)	6.74	29.1	2.80	4.56	67.62	**Orchard (N=43)**	0.12	10.29	7.20	0.01	10.67
Bare floors(N=4)	1.06	11.53	2.79	0.43	41.04	**Floors bare (N=783)**	25.56	648.31	32.05	3.22	12.60
Rainfed crops (N=28)	150.17	685.36	13.98	29.13	19.39	**Rainfed crops N=492)**	134.20	2377.82	51.31	79.24	59.04
Surfaces water (N=3)	2.68	20.04	3.05	1.80	67.18	**Surfaces water (N=94)**	4.63	73.69	8.55	2.10	45.45

Source: CGNDB 2002/Sentinel Image-2B 2021 (Path 195, Row 52) ; Laboratory work, January 2022

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Thus, with the exception of the savannah class, the size and shape of the rain-fed crop patches and bare ground in 2021 characterize a significant level of anthropization in the study area. Figure 3 shows, from the reference polygon (randomly identified in the study area), the different shapes of certain occupation units in 2002 and 2021. This illustration is also interesting in that it shows, from one case, the changes from 2002 to 2021. Thus, we can see from this figure a deep fragmentation of the savanna into bare soil and rainfed crops.

The dominance (D) reflects the level of fragmentation of the space. The lower the value of dominance, the more fragmented the class (Mouahamoudou and al. 2012). The opposite effect, i.e. a dominance with an upward trend, reflects a certain stabilization of the said class. As a reminder, fragmentation is an analysis method generally applied in landscape ecology (Flowers and al. 2020). It is interested in the study of the structure and dynamics of spatial mosaics (Wiens, 1999). It was used in this study to know the degree of fragmentation and conversion (change) of spatial structures of the study area. Analysis of the dominance values shows a decreasing trend from 2002 to 2021. The results show that some classes have experienced significant fragmentation. Indeed, the dominance indices of classes such as savannah, orchards, bare soil, and water surfaces have decreased from 25.53 to 10.85; 67.62 to 10.67; 41.04 to 12.60; 67.18 to 45.45, respectively. We can underline that in 21 years the spots that dominated these classes have been broken up. Figure 3 above shows an exampleof the fragmentation of the 2002 savanna cover class into bare soil, rainfed crops and orchards in 2021.

However, rainfed crops have a particular character by their stabilization trends. Indeed, the dominance has increased from 19.39 in 2002 to 59.04 in 2021. This reflects a lesser fragmentation of this land use unit.

In view of these results on the dominance index, the commune of Sourgou presents a highly fragmented landscape. Calculations of the form and dominance indices can be completed by an analysis of the state of land use and the calculation of the average annual rate of spatial extension of the units.

3.1. Analysis of land use dynamics from 2002 to 2021

3.1.1. Land use status in 2002 and 2021

The land use status in 2002 and 2021 can be seen in Figure 4, which also shows the proportions of the different classes. Overall, there is a variation in the proportions from one class to another and from one series to another. In 2002, the land use units identified had the following rates: 39.60% savannah, 2.54% orchards, 0.4% bare soil, 56.45% rainfed crops and 1.01% water surfaces. In 2021, we note 38.16% for savannahs, 0.05% for orchards, 9.61% for bare soil, 50.45% for rainfed crops and 1.74% for water surfaces. Thus, the "rainfed crop" land use class is dominant in both 2002 (56.45%) and 2021 (50.45%). In the rural commune of Sourgou, which is also a predominantly agricultural commune. The following section analyzes the spatial dynamics of land use in the study area based on thecalculation of spatial expansion rates.

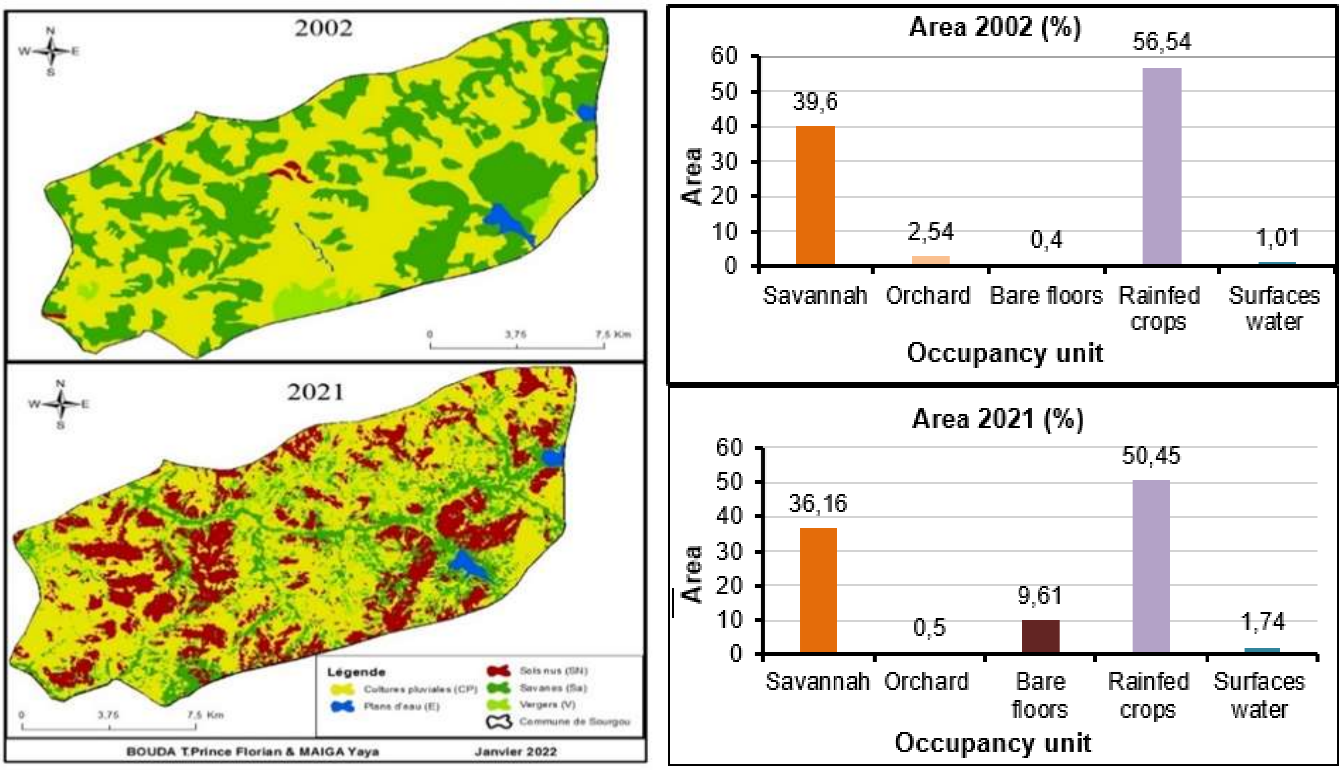


Figure 4. Land use status in 2002 and 2021

Source: CGNDB 2002/Image sentinel-2B 2021 (Path 195, Row 52); Laboratory work, January 2022

3.1.2. Spatial dynamics of land use from 2002 to 2021: calculations of spatial expansion rates

Calculations of the spatial expansion rates of the land use classes allowed for an analysis of thespatial dynamics of the land use of the study site. The positive values of the spatial expansion rates reflect a spatial evolution of this unit, while the negative ones allude to a regression. Thus, Table 3 reveals a change in bare soil and water surfaces in the study area. This increase in surface area is observed with proportions of 9.21% and 0.73% respectively. In addition, certain occupation units such as savannahs, orchards and rainfed crops have experienced a regression in their surface areas with respective rates of -1.45%, - 2.49% and - 6.00%.

Table 3. Spatial expansion rates from 2002 to 2021

Occupancy units	**2002**		**2021**		**Varia-tion** %	**TES %.**
	Area Km^2	Proportion %	Area Km^2	Proportion %		

Savannah	105.35	39.60	101.50	38.16	-1.45	-0.03
Orchard	6.74	2.54	0.12	0.05	-2.49	-3.33
Bare floors	1.06	0.40	25.56	9.61	9.21	2.67
Rainfed crops	150.17	56.45	134.20	50.45	-6.00	-0.09
Water surfaces	2.68	1.01	4.63	1.74	0.73	0.45

Source: CGNDB 2002/Image sentinel-2B 2021 (Path 195, Row 52); Laboratory work, January 2022

Also, the analysis of the transition matrix (Table 4) shows that the increase in the area of watercourses in 2021 is justified by a loss of area of certain occupation units such as bare soil (0.03 km2), savannahs (1.56 km2) and fields (0.99 km2) to the benefit of those ofwatercourses. The increase in the area of watercourses is also explained by the developmentof new hydro-agricultural infrastructure, the most important of which is the hydro-agriculturaldam at La in 2018. Also, the increase in bare soil area in 2021 is explained by the fact that certain occupation units have given up portions of their surfaces. These occupation units are: orchards (0.37 km2), savannahs (18.40 km2), fields (6.66 km2) and waterways (0.10 km2).

Table 4. Transition matrix

		2002						
		Orchards	Soils nude	Savanna h	Culture	Course water	Row Total	Class Total
2021	Orchard	**0**	0	0.01	0.10	0	603600	603600
	Bare floors	0.37	**0.01**	18.40	6.66	0.10	39299600	39299600
	Savannah	2.88	0.62	**38.90**	58.71	0.41	174897600	174897600
	Fields	3.46	0.38	46.34	**83.89**	0.13	223868000	223868000
	Water	0	0.036	1.56	0.99	**2.04**	7240400	7240400
	Class To-tal	6.73	1.06	105.22	150.37	2.70	0	0
	Class Changes	6.73	1.05	66.31	66.48	0.66	0	0
	Image Diffe-rence	-6.13	38.23	69.67	73.49	4.53	0	0

Source: CGNDB 2002/Image sentinel-2B 2021 (Path 195, Row 52); Laboratory work, January 2022

4. Discussion

The diachronic analysis carried out from Landsat satellite images allows to highlight the evolution dynamics of land use

units. Remote sensing and spatial analysis are appropriate tools for this study, as was the case for the studies of Mouhamadou and al. (2012), Somé (2010), Kékélé (2015), Ali and Rufin (2022), Tiamiyu et al. (2023), and the work of Mouhamadou (2019). According to (Mouhamadou 2019), for the outcome of a good study on the dynamics of land use from satellite images it is necessary ideally, to use images obtained by the same sensor (or equivalent) and recorded using the same spatial and spectral resolutions, the same geometry of observation and date of acquisition. This step is a limitation to our work, because the use of the image concerned only that of 2021. As for the second image, in order to conform the previous data to the current realities, the transformation of the BDOT (Land Use Base), provided by the IGB (Burkina Geographical Institute) in 2002 was necessary. On the other hand, for the period of 2021, because of the noise on certain months, the month of November was chosen. The choice of the BDOT was made by Kékélé (2015), which also uses this basis for land use unit classification. Also, Kaufman and Seto (2001) acknowledge that highlighting changes through remote sensing can be done through several methods.

Thus, remote sensing has made it possible to show the dynamics of land use units in the commune of Sourgou from the years 2002 and 2021. At these dates, the following indices were calculated spatial structures such as the *Landscape Shape Index* (Théberge 2003), dominance,spatial expansion rate. Authors such as Mouhamadou et al. (2012), Mouhamadou (2019), Traoré et al. (2021), on the use of these spatial indices have confirmed the interestof these indices as support to the processing of satellite images showing the fragmentation oflandscape. Otherwise, according to Mouhamadou et al. (2019) it is no longersufficient to use data obtained by remote sensing with certainty in the results of work, if theassociated errors are statistically ignored. The calculation of indices is therefore timely. Thismethod, generally applied in landscape ecology, makes it possible to know the degree ofartificialization (Ducrot 2005) and desertification (Hountondji 2008) of agiven area. Also, Bastien (2001) recognizes that landscape ecology must be accompanied by the use of remote sensing methods, GIS, and spatial statistics because itcannot act on its own. Newton and al. (2009) suggest a close relationship betweenthese two disciplines by a greater integration of remote sensing methods with ecological data. In our case of study, it allows to understand that the anthropic activities constitute the mainfactor of the changes operated within the commune. Thus, the geography through thesehuman and physical processes as underlined Marty et al. (2006), allows to explain the dynamics of the landscape.

In the commune of Sourgou, the evolution of land use units reflects the control of man; theuse of remote sensing highlights a positive evolution of surfaces such as bare soil and water surfaces. The evolution of water surfaces in the study area is consecutive to the intervention ofprojects for the development and rehabilitation of micro-dams in the said commune for irrigated purposes (Maïga 2020). Like these two units, other units such as rainfed crops, savannahs and orchards are experiencing regression. This loss of rainfed crop, savanna and orchard areas is congruent with the results of Kékélé (2015) who shows a trend of abandonment of these units in favor of fruit growing in western Burkina. As for our study site,the trend is more towards adaptation through conversion to market gardening (Bouda 2020).

5. Conclusion

The study of land use in the rural commune of Sourgou reveals a landscape dynamic of land use units from 2002 to 2021. This dynamic is perceptible through the rates of spatial expansion. The study shows a regression of units such as water surfaces and bare soil to the detriment of other units such as savannahs, rainfed cropsand orchards in the study series. In addition, the evolution of the degree of artificialization of the study area can be seen in the size and shape of the land use units. The determination of dominance indices in this work shows a greater fragmentation of all land use units except for rainfed crops, which are less

fragmented. In other words, during the 19-year series, agricultural areas did not experience much segmentation or conversion to another land use unit.

Thus, these results lead to a categorization of the land use classes of the study site in two scales, namely the weakly changed and more fragmented units (savannah, orchards, rainfed crops) which show a reconversion to other activities and those changed and less fragmented (water surfaces and bare soil) resulting from the strong presence of human activities in the study area, and the demographic pressure.

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